EVENSON, McKEOWN, EDWARDS & LENAHAN, P.L.L.C.
1200 G Street, N.W., Suite 700
Washington, D.C. 20005
(202) 628-8800

March 13, 2000

Box PATENT APPLICATION
Assistant Commissioner for Patents
Washington, D.C. 20231

Re: New U.S. Patent Appln.
Our Ref: 218TG/48722

Sir:

Transmitted herewith for filing is the patent application of: Peter HEINRICH et al.

entitled: QUALITY ASSURANCE DURING THERMAL SPRAY COATING BY MEANS OF COMPUTER PROCESSING OR ENCODING OF DIGITAL IMAGES

Enclosed are:

1. Specification, including 22 claims (20 pages).

2. 2 Sheets of x Formal ______ Informal drawings showing Figs. 1 - 3

3. X Declaration and Power of Attorney **(unexecuted)**.

4. Assignment of the invention to Linde Technische Gase GmbH.

5. Priority is being claimed under 35 U.S.C. §119 and 37 C.F.R. §1.55 based on Priority Document 19910892.7, filed in Germany on March 11, 1999.

The filing fee is being deferred.

Respectfully submitted,

Donald D. Evenson
Registration No. 26,160
Vincent J. Sunderdick
Registration No. 29,004

DDE:VJS:tvg

H:\lib\docs\218TG\48722\APPS\BH3070.WPD

Attorney Docket No. 218TG/48722
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

SPECIFICATION

INVENTION: QUALITY ASSURANCE DURING THERMAL SPRAY COATING BY MEANS OF COMPUTER PRECESSING OR ENCODING OF IMAGES

INVENTOR: **Peter HEINRICH**
Citizenship: German
Post Office Address/ Residence: 82110 Germering, Germany *

INVENTOR: **Werner KROEMMER**
Citizenship: German
Post Office Address/ Residence: Matthias-Gruenwald-Weg 12
84034 Landshut *

INVENTOR: **Dr. Klaus LANDES**
Citizenship: German
Post Office Address/ Residence: Melchiorstr. 23
81479 Muenchen *

INVENTOR: **Jochen ZIERHUT**
Citizenship: German
Post Office Address/ Residence: Friedrich-Ebert-Str. 14b
85521 Ottobrunn *

INVENTOR: **Tilo STREIBL**
Citizenship: German
Post Office Address/ Residence: Josef-Kyrain-Str. 14
85579 Neubiberg *

ATTORNEYS: EVENSON, McKEOWN, EDWARDS & LENAHAN, P.L.L.C.
Suite 700
1200 G Street, N.W
Washington, D.C. 20005
Telephone No.: (202) 628-8800
Facsimile No.: (202) 628-8844

TITLE OF THE INVENTION

QUALITY ASSURANCE DURING THERMAL SPRAY COATING BY COMPUTER PRECESSING OR ENCODING OF DIGITAL IMAGES

BACKGROUND AND SUMMARY OF THE INVENTION

This application claims the priority of German Patent Document 199 10 892.7, filed March 11, 1999, the disclosure of which is expressly incorporated by reference herein.

The present invention concerns a thermal spray coating method for creating a coating layer on the surface of a substrate, wherein at least one characteristic of the thermal spray coating method affecting the quality of the coating layer is recorded, controlled, and/or monitored by a digital camera. The present invention also concerns a device for quality assurance when creating a coating layer on the surface of a substrate by thermal spray coating which comprises a digital camera for recording, controlling, and/or monitoring at least one characteristic of the thermal spray coating method affecting the quality of the coating layer.

In the thermal spray coating method, typically an additive is melted onto or applied in molten form with the aid of a gas or gas mixture to the surface of the substrate to be coated.

A method and a device of this kind are described in our German patent application 198 20 195.8. The starting point in

that application was to guarantee reproducibility; achievement of quality demands; and adherence to prescribed quality requirements by recording, controlling, and/or monitoring the parameters in thermal spray coating. To do so, relevant process parameters are measured, controlled and perhaps also documented. Such parameters could be, for example, gas flows (carrier gas and/or perhaps fuel gas); current strengths; the spraying distance; the spraying angle (angle between the coating jet and the substrate surface); the velocity of the coating jet relative to the substrate surface; the quantity of additive taken up; the quantity of sprayed powder or the wire feed rate; and the like.

Within the scope of this present invention, all known variants of thermal spray coating would in principle be feasible as process variants, for example, autogenous flame coating, high velocity flame coating, plasma coating, electric arc coating, detonation coating or laser coating, and also the thermal coating variant known as cold gas coating, which is a type of further development of high velocity coating (for example, as described in the European patent specification EP 0 494 533 B1). In cold gas coating, an additive is in powder form in which the powder particles are not melted in the gas jet during cold gas coating. Instead, the temperature of the gas jet is kept below the melting point of the additive powder particles.

In the device as described in our German patent application 198 20 195.9, a digital camera is provided for recording, controlling, and/or monitoring at least one characteristic of the thermal spray coating method affecting the quality of the coating layer. The digital cameras could be either digital image cameras or digital video cameras. The required recording, controlling, and/or monitoring could therefore be achieved by single images and/or video images combined together as sequences to make a film. The boundary between single images on the one hand and film on the other hand is not sharply defined. The lower limit for the frame frequency can be regarded as approximately 16 images per second given the slow response of the human eye.

The diagnostic for recording, controlling, and/or monitoring of characteristics of the thermal spray coating method affecting the quality of the coating layer, as described in our German patent application 198 20 195.9, allows quality assurance of the thermal coating process with relatively little effort yet with exceptional efficiency. So, for example, in companies where thermal coating is used and at the same time frequent changing of coating applications arises, the reproducibility of the coating layer can be guaranteed, and consistent quality of the coating layers very quickly achieved by a diagnostic that evaluates quality-influencing characteristics or parameters and/or quantitatively measures the spray coating method using image standards. It is important, due to the purely optical

approach used, that the recording, controlling, and/or monitoring of the quality characteristics in no way whatsoever adversely affects the thermal spray coating method or damages the coating layer in any way. On the other hand, for example, it can be guaranteed even after a longer period of time that the same application is coated with the same coating accuracy if, for example, the characteristics of the image in the melting zone are identical to the previous ones.

The recording, controlling, and/or monitoring by a digital camera can be used to control and, if necessary, optimize one or more parameters. With digital technology, it is completely unproblematic to display and/or evaluate, during the running spray coating process, the recordings made for the purpose of recording, controlling, and/or monitoring the quality of the coating layer so that optimized control of the spray coating parameters can take place. This optimization of the parameters contributes to the economic efficiency of the thermal spray coating method because an ineffective high consumption of one or more of the materials required by the thermal spray coating method (e.g., gas volumes, additives) is avoided, thus allowing savings to be achieved.

In doing so, advantage can be taken of the many display possibilities that digital technology provides. Depending on the individual case, the various display variants - in particular

computer processing or encoding - can provide particular advantages. The images or video recordings can in principle be presented in black and white or color. Mixed forms with, for example, partial color representation are also possible.

The task of the present invention is to provide a method and a device as described at the outset wherein the computer processing and/or encoding has been further developed and improved. In particular, the volume of information upon which the diagnostic is based is to be kept as small as possible or reduced so as to simplify handling, speed, and/or data storage.

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the individual stages of an image processing method for quality assurance in thermal spray coating in accordance with the present invention as a series of images;

Figure 2 is a system for generating the digital image processing according to the present invention; and

Figure 3 is a flow chart detaching the image processing according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the images according to the method of the present invention, at least one area of equal intensity and/or at least one area within a particular intensity interval is assigned to one or more symmetric geometrical surface regions by computer processing and/or encoding.

In the device according to the present invention, means are provided for recording the one or more symmetric geometrical surface regions as a data record or records, based on the typical characteristics of the respective geometric shape, whereby at least one of the characteristics of the spray coating method affecting the quality of this coating layer can be stored, controlled, and/or monitored by means of this data record or these data records.

The symmetry of the geometrical surface regions includes, within the scope of the present invention, axial symmetry and rotational symmetry.

In designing the present invention, the one or more symmetric geometrical surface regions are recorded as a data record or data records based on the typical characteristics for the respective geometric shape and at least one of the characteristics of the thermal spray coating method affecting the

quality of the coating layer is recorded, controlled, and/or monitored by this data record or data records.

The particular symmetric geometrical surface regions used are circles, squares, rectangles, parallelogram, and/or ellipses. Of those, ellipses are preferentially used because oval structures are formed as a rule which, because of their similar contour to ellipses, can be recorded easily and relatively precisely.

It is advantageous to record independent typical characteristics as a data record for the respective geometric shape. This helps to keep the quantity of data small and to obtain the most respective data possible.

The computer processing and/or encoding is preferably carried out by a contour detection algorithm; by a gradient steps representation; and/or by a gradient accentuating representation reduced to bit planes.

The at least one characteristic of the thermal spray coating method affecting the quality of the coating layer could relate to the spray coating method itself and/or the spraying device being used.

The symmetric geometrical surface regions or preferably their data records can be used to control and possibly optimize one or more parameters.

It is also possible for the symmetric geometrical surface regions or preferably their data records to be used to document one or more of the characteristics affecting the quality of the coating layer and/or the spray coating method itself.

The present invention enables quality assurance by a diagnostic on the basis of relatively (with regard to the large number of parameters in thermal spray coating) small quantities of data and based on representative and unique data for the spray coating method or the spraying device.

With regard to the spraying device (burner) the following conclusions can be drawn directly from the geometrical surface regions or preferably their data records:

- for the plasma burner example (plasma coating):
  - state of the electrodes,
  - enthalpy changes in the free jet, and
  - the enthalpy distribution in the free jet.

- for the HVOF burner example (high velocity flame coating):

- velocity of the discharged gas (separation of the ultrasonic nodes),
- enthalpy changes in the free jet, and
- the enthalpy distribution in the free jet.

The following characteristics of the spray coating method (i.e. the particular jet) can, for example, be recorded from the geometrical surface regions or preferably their data records: (1) melting behavior; (2) aperture; (3) center-of-mass; and (4) direction.

The present invention will now be described in more detail with the aid of an example. Figure 1 shows the individual stages of an image processing method for quality assurance in thermal spray coating in accordance with the present invention (e.g., plasma coating) as a series of images. The individual stages are:

1. Image recording,
2. Contour detection,
3. Ellipse fitting,
4. Ellipse characterization, and
5. Database.

The sequence of images is based on a computer processing and/or encoding method in accordance with the present invention.

Areas of equal intensity in the exposed image sections are marked by a contour detection algorithm, a gradient steps representation, or a gradient accentuating representation reduced to bit planes. This information, representative of both the state and the operation of the spraying device (burner) and of the state and progress of the spray coating method are then used as information carriers for further processing.

One or more ellipses are fitted to the resulting oval structures. In doing so, each ellipse is fully characterized by means of its five independent properties. The properties are:

- vertical position of the ellipse center-of-mass,
- horizontal position of the ellipse center-of-mass,
- length of semi-axis 1,
- length of semi-axis 2, and
- angle of one of the semi-axes to the horizontal.

Figure 2 illustrates an arrangement to accomplish the imaging and processing of the present invention. A digital camera records images of thermal spray coating of a substrate 80 by way of a sprayer 90. The digital images captured by camera 70 are fed to a computer 30 having a microprocessor 40, ROM 60 and a storage device 50 in the form of a CD, CD-ROM, floppy disk, or other media. A keyboard 20 and a monitor 10 complete the system.

The processing of the digital image from the camera 7 is detailed in Figure 3 wherein the digital image 110 is fed to a contour detector 120 which provides an outline of the geometric shape. The resulting contour is analyzed and compared to a series of ellipses at 130 to find the closest fit for particular portions of the region of the image. The resulting closest fitting chosen ellipses are then subjected to analysis at 140 to determine their characteristics including the five above discussed independent properties.

The computer processed or encoded image representation leads to a data record 150 of these independent properties of one or more ellipses which, with regard to quality assurance in thermal spray coating method (in a wider sense), characterizes both the spraying device and the spray coating method itself (in a narrower sense).

By this means the information of the entire spray coating method can be reduced to a small quantity of very representative, unique information that allows a simple, mathematically supported process diagnostic to be realized.

The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons

skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.

WHAT IS CLAIMED IS:

1. A thermal spray coating method, comprising:

recording, controlling, and/or monitoring at least one characteristic of the thermal spray coating method affecting the quality of the coating layer by creating images with a digital camera; and

assigning the images of at least one region of equal intensity and/or at least one region within a particular intensity interval to one or more symmetric geometrical surface regions by computer processing or encoding.

2. A thermal spray coating method according to Claim 1, wherein said at least one characteristic of the thermal spray coating method affecting the quality of the coating layer is selected from the group consisting of gas flows, current strengths, spraying distance, spraying angle, a velocity of a coating jet relative to a substrate surface, and a quantity of sprayed powder.

3. A method according to Claim 1, wherein said assigning comprises recording the one or more symmetric geometrical surface regions as a data record based on independent typical characteristics of the respective geometric shape.

4. A method according to Claim 3, further comprising recording, monitoring, and/or controlling at least one of the

characteristics of the thermal spray coating method affecting the quality of the coating layer by means of the data record.

5. A method according to Claim 1, wherein the symmetric geometrical surface regions are selected from the group consisting of circles, squares, rectangles, parallelograms, ellipses, and combinations thereof.

6. A method according to Claim 1, wherein the symmetric geometrical surface regions are ellipses.

7. A method according to Claim 3, wherein the independent typical characteristics are recorded as a data record for the respective geometrical shape.

8. A method according to Claim 1, wherein the computer processing and/or encoding is carried out by at least one of a contour detection algorithm, a gradient steps representation, or a gradient accentuating representation reduced to bit planes.

9. A method according to Claim 1, wherein the at least one characteristic of the thermal spray coating method affecting the quality of the coating layer relates to at least one of the spray coating method or a spraying device.

10. A method according to Claim 3, further comprising controlling or optimizing one or more parameters of the thermal spray coating process with the symmetric geometrical surface region or the data record.

11. A method according to Claim 3, further comprising documenting one or more characteristics affecting the quality of the coating layer and/or the spray coating method using the symmetric geometrical surface regions or the data record.

12. A device for quality assurance of a thermal spray coating layer on the surface of a substrate, comprising:

a digital camera for recording, controlling, and/or monitoring at least one characteristic of the thermal spray coating method affecting the quality of the coating layer in digital images;

a computer processing and/or encoding device; and

means for assigning at least one region of equal intensity and/or at least one region within a particular intensity interval in the digital images to one or more symmetric geometrical surface regions by said computer processing and/or encoding device.

13. A device according to Claim 12, wherein said means for assigning comprises means for recording the one or more symmetric geometrical surface regions as a data record based

on characteristics of the respective geometric shape and said device further comprises means for recording, controlling and/or monitoring at least one characteristic of the thermal spray coating method affecting the quality of the coating layer.

14. A device according to Claim 13, further comprising means for controlling or optimizing one or more parameters of the thermal spray coating based upon the data record.

15. A device according to Claim 13, wherein the device comprises means for documenting one or more of the characteristics affecting the quality of the coating layer and/or the spray coating method using the symmetric geometrical surface regions or the data record.

16. A computer program product for use with a digital camera producing a digital image of an event, said computer program product comprising:

a computer usable medium having computer readable program code means embodied in said medium for causing the assignment of a digital image from the camera to a series of relationships between particular intensity levels of the image and particular geometrical surface regions in order to monitor the quality of the event, said computer program product having;

computer readable program code means for causing a computer to effect, with respect to each image, a determination of the boundaries of various intensity levels of said image;

computer readable program code means for causing said computer to store in an array values representing the boundaries of the various intensity levels of said digital image and means for causing said computer to compare said stored boundary values of said images with stored values for one or more symmetric geometrical surface regions and to chose the closest matches for each of said various intensity levels resulting from said comparison;

computer readable program code means for causing said computer to determine a plurality of characteristics of said chosen symmetric geometrical surface regions and compile a listing of said characteristics as a data base in order to monitor quality of the event.

17. The computer program product according to claim 16, wherein the event is a thermal spray coating.

18. The computer program product according to claim 16, wherein said symmetrical geometrical surface regions are ellipses.

19. A program storage device readable by a machine tangibly embodying a program of instruction executable by the machine to perform method steps for monitoring the quality of

thermal spray coating of a substrate, said method steps comprising:

producing digital images of a thermal spray coating of a substrate;

storing said digital image and determining boundary values of regions of intensity of said digital image;

comparing said boundary values with a plurality of symmetric geometrical surface regions and determining ones of said geometrical regions which most closely match boundary values of said regions of intensity of said stored digital image;

characterizing said selected ones of said symmetric geometrical surface regions as a function of size and position;

compiling a list of characteristics based on said size and position of said selected geometrical regions and providing a database which serves as a monitor of the characteristics of the thermal spray coating.

20. The program storage device according to claim 19, wherein said symmetric geometrical regions are ellipses.

21. The program storage device according to claim 20, wherein said characteristics include at least one of a vertical position of the ellipse, center-out-mass, a horizontal position of the ellipse center-out-mass, a length of first and second semi-axes, and an angle of one of the semi-axes to the horizontal.

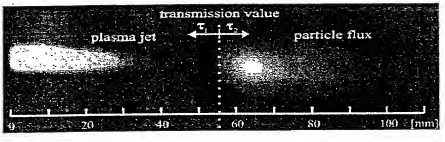
22. The computer program product according to claim 18, wherein said characteristics include at least on of a vertical position of the ellipse center-out-mass, a horizontal position of the ellisp center-out-mass, a length of first and second semi-axes, and an angle of one of the semi-axes to the horizontal.

ABSTRACT OF THE DISCLOSURE

A thermal spray coating method for creating a coating layer on a surface of a substrate is monitored by determining characteristics of the thermal spray coating as it affects the quality of the coating layer by recording, controlling, and monitoring through a digital camera whose image is analyzed and characterized.

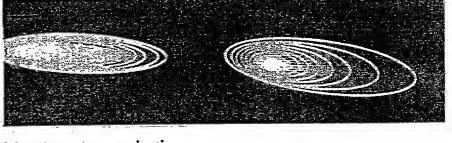
Fig. /

a) Image recording

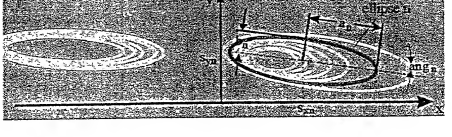


b) Contour detection

c) Ellipse fitting



d) Ellipse characterization



e) Database

result: data bank

sx1:0.05635	sy1:0.00332	ang1:0.00251	a1:0.90845	b1:5.44042
sx2:0.06343	sy2:0.00631	ang2:0.00089	a2:5.63184	b2:6.53315
sx3:0.65433	sy3:0.00123	ang3:0.00068	a3:9.81134	b3:5.54042
...	...	...	...	...

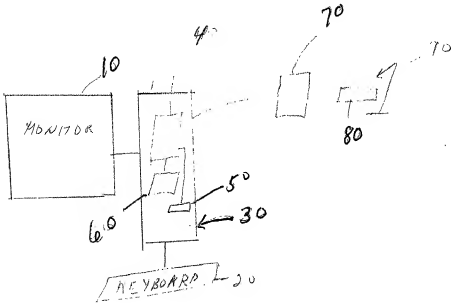


FIGURE 2

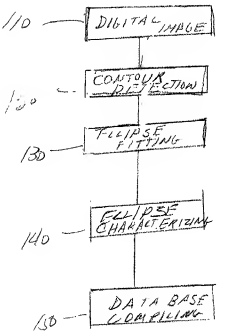


FIGURE 3

Attorney Docket No. 218TG/48722

DECLARATION AND POWER OF ATTORNEY - PATENT APPLICATION

As a below named inventor, I hereby declare that my citizenship, postal address and residence are as stated below; that I verily believe I am the original, first and sole inventor (if only one inventor is named below) or a joint inventor (if plural inventors are named below) of the invention entitled:

QUALITY ASSURANCE DURING THERMAL SPRAY COATING BY MEANS OF COMPUTER PRECESSING OR ENCODING OF IMAGES

the specification of which

X is attached hereto, or

____ was filed on _____ as Application Serial No. _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose all information known to be material to patentability as defined in 37 CFR §1.56. I hereby claim foreign priority benefits under Title 35, United States Code §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)		Priority Claimed	
19910892.7 (Number)	Germany (Country)	11/3/99 (Day/Month/Year)	Yes
_____ (Number)	_____ (Country)	_____ (Day/Month/Year)	____

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose all information known to be material to patentability as defined in 37 CFR §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status)

I hereby appoint as principal attorneys Martin Fleit, Reg. No. 16,900; Herbert I. Cantor, Reg. No. 24,392; James F. McKeown, Reg. No. 25,406; Donald D. Evenson, Reg. No. 26,160; Joseph D. Evans, Reg. No. 26,269; Gary R. Edwards, Reg. No. 31,824; Jeffrey D. Sanok, Reg. No. 32,169; and Richard R. Diefendorf, Reg. No. 32,390, to prosecute and transact all business in the Patent and Trademark Office connected with this application and any related United States and international applications. Please direct all communications to:

Evenson, McKeown, Edwards & Lenahan, P.L.L.C.
1200 G Street, N.W., Suite 700
Washington, D.C. 20005
Telephone: (202) 628-8800
Facsimile: (202) 628-8844

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

INVENTOR: **Peter HEINRICH**
Citizenship: German
Post Office Address/ Residence: 82110 Germering, Germany
*

(date) (signature of 1st inventor)

INVENTOR: **Werner KROEMMER**
Citizenship: German
Post Office Address/ Residence: Matthias-Gruenwald-Weg 12
84034 Landshut
*

(date) (signature of 2nd inventor)

INVENTOR: **Dr. Klaus LANDES**
Citizenship: German
Post Office Address/ Residence: Melchiorstr. 23
81479 Muenchen
*

(date) (signature of 3rd inventor)

INVENTOR: **Jochen ZIERHUT**
Citizenship: German
Post Office Address/ Residence: Friedrich-Ebert-Str. 14b
85521 Ottobrunn
*

(date) (signature of 4th inventor)

INVENTOR: **Tilo STREIBL**
Citizenship: German
Post Office Address/ Residence: Josef-Kyrain-Str. 14
85579 Neubiberg
*

(date) (signature of 5th inventor)